

Block Copolymer Nanolithography



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Block copolymer technology has been used increasingly for patterning nanoscale features in polymers, silicon and metals. Highly-ordered nanoscale features are produced in thin (nanometer-thick) self-assembled films. In diblock copolymer systems these films consist of two covalently bonded polymer chains. These systems form distinct domain structures due to phase separation of the chemically dissimilar polymers during solidification. Depending on the relative volume fraction, domains can form as spheres, cylinders, or lamellae oriented either perpendicular to or parallel to the surface with a period on the order of 10 to 100 nm.

Recently, advanced directed block copolymer self-assembly is showing great promise for controlled nanolithography techniques for achieving advanced SEMI lithography nodes and high-density periodic pore arrays and gratings. Still others have demonstrated the potential of nanofeature masks for fabricating components for micro- and optoelectronics, magnetic storage devices, nanopore

membranes and nanotemplates for ordered detector arrays.

Project Goals

Our interest in block copolymers has been to leverage existing efforts in order to establish a core nanolithography capability. First year goals were to form a collaboration to assist in the definition and stand-up of a diblock copolymer process within LLNL. This process was based on the polystyrene (PS) and polymethylmethacrylate (PMMA) diblock copolymer. A second goal was the dimensional characterization of these nanostructures using existing analytical tools including SEM, AFM, and TEM. An additional goal of this effort was to incorporate findings from an associated modeling effort to prescribe block copolymer specifications for dimensional characterization and parametric studies. Second year goals include a continued use and refinement of predictive modeling for the 2-D process and extension toward 3-D nanolithography.

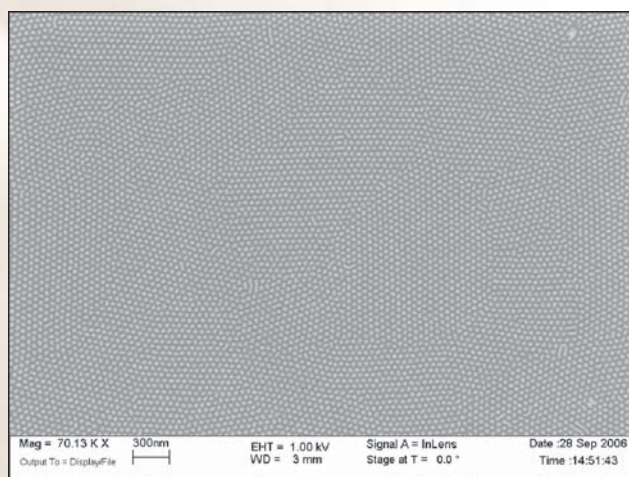


Figure 1. SEM of self-assembled DiBCP thin film with ~ 60 nm period. The hex pack PS (light gray) cylinders are vertically oriented and ~ 30 to 35 nm in diameter.

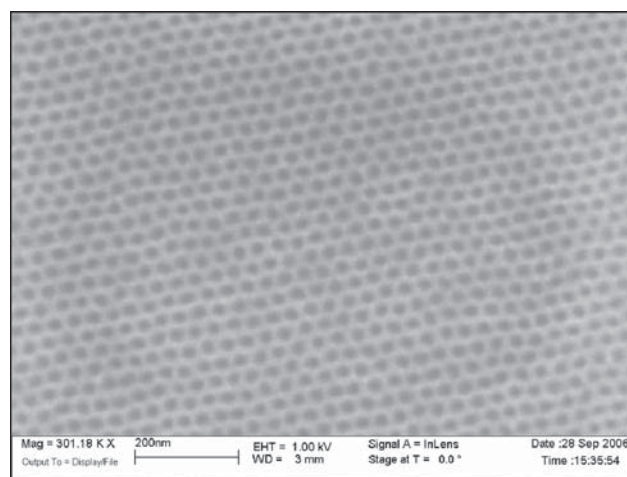


Figure 2. SEM of a 40-nm period thin film produced by etching out the spherical PMMA domain, leaving a PS (light gray) mask.

Relevance to LLNL Mission

Reducing a block copolymer nanolithography process technology to practice maps directly onto LLNL's Micro/Nano-Devices and Structures roadmap initiative. This is an enabling technology that will initially provide a capability of nanoscale mask lithography with applications to NIF targets and sensor systems integration for NHI and DNT. Example applications include x-ray gratings, nanobridge wires, nano-dimension antennas and resonators, high surface area for high-energy-density storage capacitors and batteries, novel radiation detectors, and graded density targets.

FY2006 Accomplishments and Results

First year efforts resulted in the demonstration of a 2-D self-assembled block copolymer process. We worked with staff at LBNL and UCB to define and establish a well-characterized PS/PMMA process at LLNL. Requisite polymers and solvents were specified and materials were procured. An experimental plan with process controls was put in place to work with solvents at high temperature to obtain monolayer films.

Cylindrical and spherical block copolymer structures were fabricated as

shown in Figs. 1 and 2. These films were characterized using SEM, and AFM to determine feature sizes as small as 25 nm (Fig. 3).

An initial wet etch process was demonstrated to remove the PMMA component in the film. This proved to be prerequisite for increasing the topology and thus contrast in the SEM observation. We worked with various volume fractions of the PS/PMMA system to demonstrate the different domain formations, including lamellae, although these were observed only in the parallel configuration. These efforts were repeated on both silicon and oxide substrates in keeping with our intent to demonstrate the utility of the process for increased surface area. These parametric studies also served to validate predictive modeling efforts. These results are providing insight to polymer system selection for proposed predictive graded-density film fabrication next year.

We also began to define and establish a dry etch process for the removal of the PMMA polymer. Process steps have been identified to pursue parametric definition of a dry process in order to fabricate robust etch masks.

Related References

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FY2007 Proposed Work

Our next efforts will focus on extension of existing processes to demonstrate 3-D nanolithography. First we plan to enhance our block copolymer fabrication capability by expanding the base process to allow for extended long range ordering. This will require control of interfaces and substrate etching for enhanced domain alignment. A parallel computational modeling effort to predict best polymer systems for extended order is also planned. This builds on FY2006 modeling efforts.

A primary FY2007 focus will be to evaluate triblock copolymers. Such films are less surface-dependent and have been shown to allow subsequent removal for building laminated structures. This, coupled with variation of block copolymer systems, will lead to varied density of films. Additionally our current process is to be expanded to permit lift-off of arbitrary thin films, such as metals. This will enable fabrication of nanometer features for surface-enhanced Raman scattering and templated carbon nanotube-based chemical sensors.

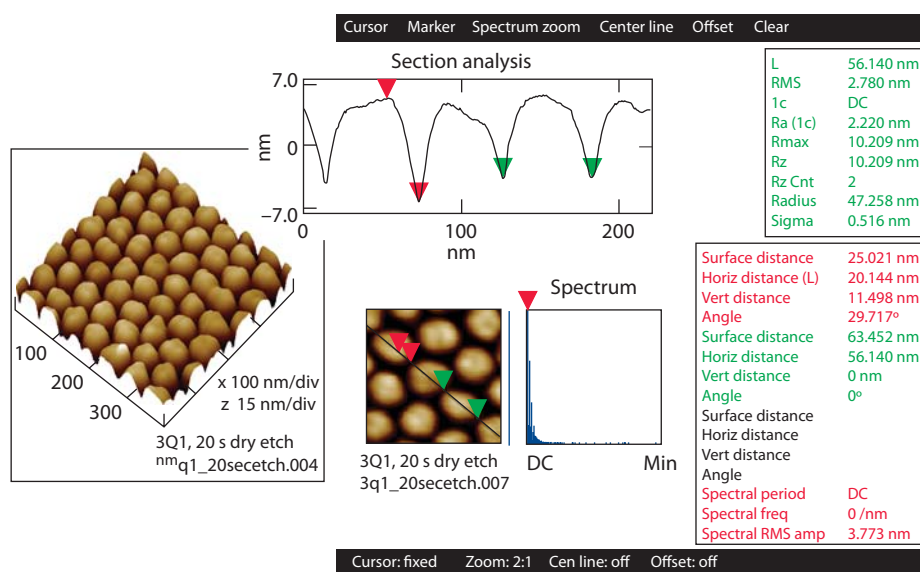


Figure 3. AFM scan of vertically-oriented cylindrical block copolymer. Cylinders are in close-pack hexagonal formation and are approximately 30 nm in diameter with a 63-nm period.